

**“State, Society, and Science: Comparative Histories of Technology in
Medieval India”**Venkatesh, Vadde¹, S, Shruthi² and R, Shantha Kumari T³¹Asst. Professor & HoD, Dept. of History, BMS College for Women²Asst. Professor & HoD, Dept. of Sociology, BMS College for Women³Asst. Professor, Dept. of History, BMS College for Women**Abstract**

The period between the 8th and 18th centuries in India saw constant discoveries because rulers and skilled workers interacted with knowledgeable individuals. The kings were not the ones who came up with new ideas and these ideas were not separate from the rest of society. New ideas developed when the people in charge the workers the merchants and the scholars and the farmers worked together. The daily life of people in the Delhi Sultanate and the Vijayanagara Empire and the Mughal Empire included new technological inventions. Indian kingdoms developed irrigation systems and constructed large buildings and developed military capabilities and expanded commercial activities. South India saw the construction of tanks while the northern regions developed canals that included the creation of intricate domes and monuments. The country developed steel production and established a successful textile sector while its citizens began to adopt guns. The creators of these objects possessed advanced knowledge in their field. The people who created these things gained their expertise through their family ties and their interactions with experienced workers and merchants who had achieved success in their professions. Indian technology developed through its connections to agricultural practices and tax collection and urban growth and overseas trade with Indian Ocean nations. People shared their knowledge in different languages, including Sanskrit, Persian and the languages that people spoke in different parts of the country. The system enabled different cultures to meet and exchange ideas with each other. Medieval India presents itself as a location that remained static throughout history while standing apart from global developments. The location presents itself as a constant source of innovation which maintained worldwide connections through its international ties.

Keywords: Medieval India, Technology, State formation, Artisans, Irrigation, Architecture, Military science, Metallurgy.

Introduction

The people of the Indian subcontinent established their political authority through military victories and ceremonial displays and their ability to control land resources and water resources and labor resources and physical assets. Empires rose and fell, dynasties competed for dominance, and courts patronized art and literature; yet beneath these visible expressions of sovereignty lay intricate technological systems that sustained power. The medieval Indian states built their material strength through a network of irrigation reservoirs and canal systems and protected cities and metalworking facilities and textile production sites and weapon manufacturing plants. The absence of these systems would have disrupted revenue collection processes and obstructed military operations and rendered city development unachievable.¹

The historical accounts of the Delhi Sultanate and the Vijayanagara Empire and the Mughal Empire have focused on three main aspects which include dynastic succession and administrative organization and cultural patronage.² The themes which explain political systems and ideological systems through their operational mechanisms leave essential operational systems required for governance unexamined. The construction of irrigation tanks and canals stabilized agrarian production; advances in metallurgy ensured the supply of tools and weaponry; textile industries generated commercial wealth; monumental architecture symbolized imperial authority; and the incorporation of gunpowder reconfigured military strategy.³ Technology served as an essential element for state power during medieval times because it created the foundation for government control.

Colonial historians between the 1800s and 1930s depicted medieval India as a time of

¹ Irfan Habib, *The Agrarian System of Mughal India, 1556–1707*, 2nd ed. (New Delhi: Oxford University Press, 1999), 3–7, 289–310.

² Satish Chandra, *Medieval India: From Sultanat to the Mughals, Vol. I: Delhi Sultanat (1206–1526)* (New Delhi: Har-Anand, 1997), 1–10; Burton Stein, *Vijayanagara* (Cambridge: Cambridge University Press, 1989), 15–22; John F. Richards, *The Mughal Empire* (Cambridge: Cambridge University Press, 1993), 1–8.

³ Peter Jackson, *The Delhi Sultanate* (Cambridge: Cambridge University Press, 1999), 191–200; Stein, *Vijayanagara*, 76–102; Jos Gommans, *Mughal Warfare: Indian Frontiers and Highroads to Empire* (London: Routledge, 2002), 136–158.

technological stagnation.⁴ The evaluations of Indian history showed negative results for India when researchers compared it to the European cultures of the early modern period and used mechanized industrial development as evidence that Indian civilization had lost its historical progress. The research findings reach their conclusions through industrial-era beliefs which established links between technological progress and the operation of factories and the expansion of industrial capitalism.⁵ European colonial scholars used European standards from the nineteenth century to assess medieval societies because they overlooked how environmental factors and institutional contexts determined the development of Indian technologies.

Recent research on historical events has refuted this historical account. The process of innovation now requires understanding the specific conditions of each situation which includes environmental limitations and existing labor frameworks and commercial connections and government systems. The agrarian economy benefits from hydraulic engineering and land management because these techniques create greater impact than mechanical production methods. The Indian Ocean trade network enabled regions to build their wealth through textile and metallurgical skills which matched the industrial output of other areas. Researchers who study medieval Indian technologies discover their historical development through adaptive experimentation and knowledge acquisition and institutional collaboration within their natural and cultural environments.

This article advances three interrelated arguments.

Firstly, medieval Indian technologies were socially embedded. This meant that technologies in India did not emerge in isolation. Rather, they came about through collaboration between rulers, craftsmen, peasants, merchants, and scholars. This allowed for the continuity and adaptation of technologies.⁶

Secondly, technological systems played a critical role in the formation of states in India. This was particularly true in the case of irrigation systems. The construction of irrigation systems expanded

⁴ James Mill, *The History of British India*, Vol. 1 (London: Baldwin, Cradock, and Joy, 1817), 344–356.

⁵ David Arnold, *Science, Technology and Medicine in Colonial India* (Cambridge: Cambridge University Press, 2000), 6–12.

⁶ Tirthankar Roy, *Traditional Industry in the Economy of Colonial India*, Cambridge: Cambridge University Press, 1999, pp15–30.

land under cultivation and helped in revenue generation. Forts and artillery systems helped in military consolidation.⁷ Technologies played a critical role in the consolidation of states.

Thirdly, medieval India was a major player in international exchange systems. Indian textiles, steel, and other manufactured products found their way to East Africa, the Persian Gulf, Central Asia, and Southeast Asia. India was not in isolation; rather, it was an integral part of international exchange systems. This meant that India was in touch with other technologies, particularly in the case of architecture, steel, navigation, and warfare.⁸

Thus, this article attempts to show how India was an integral part of international systems of exchange. However, at the same time, it attempts to show how India was able to sustain its technological systems and how technological innovations in India have to be evaluated in their own right. Rather than comparing India with other technological systems in Europe and Asia, this article attempts to show how India was able to sustain its technological systems and how this was critical to the formation of states.

Literature Review

The examination of technology from medieval India has been influenced by various historians who studied how state institutions and social systems interacted with scientific knowledge.

Irfan Habib 'The Agrarian System of Mughal India (1999) became a fundamental study which Irfan Habib conducted to examine the Mughal Empire's economic and technological development. Habib showed that Mughal officials implemented advanced techniques for calculating land dimensions and crop classification and water distribution system management. His research established that agricultural output and revenue systems depended on technological knowledge which authorities used to enforce their rule through scientific and technical methods.

Burton Stein in 'Peasant State and Society in Medieval South India (1980)' and 'Vijayanagara (1989)' used the term "segmentary state" to describe how South Indian states organized their political structure. Stein explained how his political power model distributed authority throughout various sectors including temples and local elites and village assemblies. The study showed that

⁷ Iqtidar Alam Khan, *Gunpowder and Firearms in Medieval India*, *Indian Historical Review* 29, no. 1 (2002): pp5–18; Gommans, *Mughal Warfare*, pp102–120.

⁸ Chaudhuri, *Trade and Civilisation*, 248–276; Om Prakash, *European Commercial Enterprise in Pre-Colonial India* Cambridge: Cambridge University Press, 1998, pp23–45.

agricultural production increased and social order remained stable because local organizations and irrigation tanks collaborated to create their agricultural systems which used technological systems to determine political authority.

The book *An Agrarian History of South Asia* published in 1999 by David Ludden examined how environmental and ecological factors affected agricultural development. Ludden demonstrated that irrigation systems and land management systems developed based on the ecological characteristics and environmental typicality of each region. The research demonstrates how political power together with environmental changes drove the evolution of agricultural practices throughout history.

The book *The Saga of Indian Steel* published in 2008 by R. Balasubramaniam. His research examined the production of high-carbon crucible steel which was known as wootz steel and exported to West Asia. Balasubramaniam proved that Indian metallurgists understood advanced material properties along with methods for controlling temperature and creating metal alloys.

Historians like Satish Chandra and Jos Gommans have investigated the relationship between warfare and military technology. Satish Chandra used his research about the Delhi Sultanate to demonstrate how cavalry organization and military administration and fortification systems created new warfare methods. In *Mughal Warfare* (2002) Jos Gommans studied how gunpowder weapons and artillery and cavalry tactics changed political control during the early modern period in India. The research establishes military technology as the main force that drove both territorial expansion and the development of imperial power.

The Social Construction of Technological Systems (1987) by Wiebe Bijker Thomas Hughes and Trevor Pinch presents their theory which states that technological innovation arises from social group and institutional and economic interest interactions. The framework enables scholars to study technological system development in medieval India which occurred through the collaboration of rulers and artisans and merchants and local communities.

The research shows that medieval Indian technological systems existed as integral components of social institutions and economic networks and political systems. The research concentrates on particular aspects which include agrarian systems and architecture and trade. The study requires researchers to conduct a comparative analysis which combines multiple research areas to assess the impact of technology on state formation and social structure and economic development in

different medieval Indian kingdoms. The current research investigates irrigation systems and metallurgy and textile production and military technologies through state–society interactions research.

Methodology

The research utilizes a historical research method which analyzes secondary sources to investigate state system interactions with societal changes and technological advancements during medieval Indian history from the 8th century until the 18th century. The research uses a historical–analytical approach which requires researchers to evaluate existing historical texts about irrigation systems and metallurgy and textile production and architectural structures and military technological advancements. The study uses published academic sources which include books and research articles and historical studies written by historians. The works provide insights into the economic social and political contexts which shaped technological systems during the medieval period. The research applies comparative analytical methods to investigate how various regions achieved technological progress through its study of South Indian tank irrigation systems and North Indian canal irrigation systems and the technological progress in metallurgy and textile production and military technology during different political periods which encompassed the Delhi Sultanate and Vijayanagara Empire and Mughal Empire. The study combines existing historical research to show how medieval technologies functioned as socio-technical systems which developed through state institutions and artisan communities and commercial networks. The approach provides an explanation of how technology contributed to the formation of states and the development of economies and social structures in medieval India.

Historiographical Context

The understanding of medieval Indian technology has experienced significant changes starting from the early 1900s until the present day. The state of science relationships with social structures and governmental authority established a clear pattern of changing relationships. Colonial scholars established a direct link between technological development and industrial production activities because they adopted European viewpoints and industrial concepts. The European industrial model

led to incorrect perceptions of Indian agricultural systems and irrigation systems and craft systems because these systems did not match European industrial standards.⁹

The development of economic and social history resulted in a shift from this particular perspective. Irfan Habib showed that Mughal governance depended on scientific and technical skills in areas like land measurement, irrigation management, and revenue assessment.¹⁰ The research showed how technology enabled the state to establish its authority. Burton Stein's model of the "segmentary state" highlighted the importance of local institutions in South India.¹¹ The study showed that irrigation systems and temple-based redistribution depended on social systems that operated at various levels through their organized but decentralized structure. The system of technology created a connection between governmental control and local community organization. The research conducted by Catherine Asher and George Michell about art history proved that architectural imitation does not hold true. The researchers identified creative architectural combinations that emerged in Indo-Islamic architecture through their study of architectural design. K. N. Chaudhuri joined other global historians by showing how Indian textile and steel production existed within the trade networks that connected Africa and Eurasia. The study demonstrated the interrelationship between scientific knowledge, commercial activities, and state governance systems.¹²

Recent research demonstrates that gunpowder and navigational methods and architectural styles spread between different areas but underwent local changes. The combination of these historical research changes demonstrates that medieval India functioned as an active environment where governmental structures and social connections and scientific research activities combined to create new technologies.

I. Irrigation, Ecology, and Agrarian Expansion

⁹ Deepak Kumar, *Science and the Raj: A Study of British India*, Oxford: Oxford University Press, 1995, pp18–22.

¹⁰ Irfan Habib, *The Agrarian System of Mughal India, 1556–1707*, 2nd ed. New Delhi: Oxford University Press, 1999, pp23–28.

¹¹ Burton Stein, *Peasant State and Society in Medieval South India*, Delhi: Oxford University Press, 1980, pp45–49.

¹² Catherine B. Asher and Cynthia Talbot, *India Before Europe* Cambridge: Cambridge University Press, 2006, pp 122–126; George Michell, *Architecture and Art of Southern India* Cambridge: Cambridge University Press, 1995, pp14–18.

The fiscal and structural framework of medieval Indian polities depended on agricultural production as its primary base. States throughout the subcontinent maintained their stability through two essential abilities. The ability to manage water resources together with agricultural expansion and stable income generation played a vital role in state stability across the subcontinent. The irrigation systems served as a vital connection point between ecological systems and community structures and governmental power. The hydraulic infrastructures operated as technical systems which functioned through social structures and government systems that controlled land rights and workforce management.¹³

- **Tank system on South India**

Tank irrigation serves as the primary irrigation method for South Indian agricultural areas. The semi-arid regions which cover Karnataka, Tamil Nadu and certain areas of Andhra Pradesh in peninsular India depend on tank systems for their irrigation needs. The reservoirs functioned as water storage facilities which collected monsoon runoff. The South Indian ecological system required tank irrigation as a necessary solution to its seasonal rainfall and irregular river flow patterns.¹⁴ The Vijayanagara Empire expanded its irrigation system through its developments in irrigation technology. The construction and renovation of tanks received funding from different sources according to royal grants and inscriptions and temple records. The assemblies in the villages during the Vijayanagara Empire (1336–1646) should not be viewed in isolation but in the context of a multi-layered system of governance.¹⁵ Rather than operating in a centralized bureaucratic system, the system in the villages should be viewed in the context of distributed authority in the social structure. These assemblies had jurisdiction over judicial issues, revenue assessment, and infrastructure development. Operating through the Ayyagar system indicates how governance in these areas was operationalized through the division of labor.

From a theoretical perspective, this system should be viewed in the context of a system of polycentric sovereignty. Rather than sovereignty being centered in the empire, it is distributed among overlapping jurisdictions. While the empire operated through the Mahanayakacharya in supervising these institutions, the management of resources in the agrarian sector, particularly in

¹³ David Ludden, *An Agrarian History of South Asia*, Cambridge: Cambridge University Press, 1999, pp80–85.

¹⁴ Burton Stein, *Vijayanagara*, Cambridge: Cambridge University Press, 1989, pp108–112.

¹⁵ Burton Stein, *Peasant State and Society in Medieval South India*, pp132–138.

irrigation systems, was left to the institutions in the villages. The management of tanks, canals, and embankments involves the mobilization of labor and technical expertise, both of which were embedded in the social structure.

When viewed from the perspective of the Science and Technology Studies approach, the irrigation systems of the Vijayanagara Empire can be conceptualized not merely as technological systems, but rather as socio-technical systems. In such a context, the maintenance of the technological infrastructure can be viewed as a medium for the exercise of political power. Decentralized management of irrigation systems, therefore, can be conceptualized not as a measure of weak central authority, but rather as a model of governance that relied on the institutional capabilities of the local to ensure the stability of the empire.

In such a context, the Vijayanagara Empire can be viewed as a model of how technological systems, such as the management of water resources, can reveal broader patterns of the formation of states. In such a context, the exercise of political authority can neither be viewed as centralized nor decentralized, but rather as a model of interdependence between the imperial and the local. The construction work required teams to build together while specialized professionals executed embankment design and water management tasks, which needed formal approval from temples. The control of irrigation systems determined how land rights were distributed, which taxes were collected, and how new settlements were established. Social organization and fiscal governance processes required ecological adaptation to take place.

- Canal Construction in North India

North India developed extensive canal systems because its river networks provide water resources which differ from the monsoon-dependent tank systems used in South India. The state engineering system established water diversion from the perennial river systems of the Yamuna River and other rivers in the Indo-Gangetic plain. The creation of extensive canal systems for river water irrigation purposes occurred during the Delhi Sultanate period. The project required long-term planning which involved multiple steps including canal system development and surveying activities and gradient assessment and embankment construction work.¹⁶

¹⁶ Irfan Habib, *Agrarian System of Mughal India*, Asia Publishing House, 1963 pp310–315.

The Delhi Sultanate period saw canal construction develop into the first governmental infrastructure project. Water control functions as the first method which governments used to establish power over territories by controlling agricultural production and expanding their land holdings. The operation of canals needed administrative resources which extended beyond what local authorities could manage. Canal construction required clear project design and supervision work because it did not function like tank systems.¹⁷

The phenomenon expanded during the period of Mughal Empire existence. The revenue increase from irrigation development which resulted from Mughal taxation policy established a connection between these two elements. The Ain-i-Akbari established land measurement (Zabt) and crop classification and taxation standards which depended on the land's productivity. The taxation system classified irrigated lands with different tax rates from rain-fed lands. The state management system included water works management as part of its operational framework. The state management system used canal maintenance and extension work to regulate agricultural surplus production.

The process of canal irrigation in North India functions as a hydraulic governance system according to analytical research. The management of water resources functioned as both ecological control and financial management method for the government. The state achieved agricultural stability through canal construction which increased the area available for taxation and protected farmers from monsoon weather patterns. The revenue system established by imperial powers connected peasants to agricultural work while providing them with better protection against crop losses.

Canal irrigation systems in India operated under stronger governmental control compared to South India's tank systems although both systems showed how water management affected state-society relations. The development of hydraulic technologies extended beyond technical accomplishments because these systems functioned as tools to achieve political unification. Medieval North Indian states established their governmental authority through water control while they created social order and maintained their military and urban development systems.

II. Metallurgy and Craft Knowledge

¹⁷ Satish Chandra, *Medieval India: From Sultanat to the Mughals* (New Delhi: Har-Anand Publications, 2004), 118–122.

Medieval India had a very advanced metallurgy. Indian metallurgists developed high-carbon crucible steel, also known as wootz steel, which was renowned for its strength, malleability, and decorative appearance. This was primarily produced in the Deccan and South India and was exported to the West and Central Asian countries, where it was used to produce the famous Damascus steel. This process involved using sealed crucibles to melt iron along with carbon-containing materials. This ensured that the growers could accurately control the amount of carbon in the steel. This was not simply a matter of serendipity but involved careful observation and a deep understanding of how metals changed during the process.¹⁸

Indian metalworkers were not simply limited to making steel. In South India, bronze casting in temple workshops was also indicative of great expertise and artistry. Lost-wax or cire perdue casting involves precise control over heat, mixing of metals, and mold-making. These processes demonstrate how artistic, spiritual, and scientific understanding came together in India.¹⁹

The Mughal Empire used metalworking for military and administrative objectives. In the Mughal karkhanas, which were workshops of the empire, they made cannons, guns, armor, and coins. For making big guns, they had to obtain resources and organize themselves well to melt and mold them and then move them. Gunpowder weapons used in Mughal warfare are evidence of the use of metallurgy in Mughal warfare and the expansion of the Mughal Empire.²⁰ Generally, people in metallurgy inherited their skills through family and apprenticeships in castes and guilds. This does not, however, suggest that there was no change. People changed and improvised techniques to accommodate new market requirements, including international trade and warfare. Metallurgical knowledge is a living system that is related to family but also to the economy and politics. In general, metallurgy in medieval India suggests that science is a part of artisanal culture, not a separate academy. Experiments were conducted in workshops, and innovation resulted from improvement, not creation, of what was already known. Exports of wootz steel and the production of military equipment suggest that metallurgical knowledge was important, not just limited to local regions. This is evidence of increasing knowledge, which is a result of resources, labor, and trade.

¹⁸ R. Balasubramaniam, *The Saga of Indian Steel*, New Delhi: Rupa Publications, 2008, 44–52

¹⁹ Vidya Dehejia, *Indian Art*, London: Phaidon Press, 1997, 146–149

²⁰ Jos Gommans, *Mughal Warfare: Indian Frontiers and High Roads to Empire* (London: Routledge, 2002), 143–150.

III. Textiles and Commercial Expansion

The era from the fourteenth century to the seventeenth century saw Indian textiles as one of the major contributing factors to the development of commercial activities in the Indian Ocean region. The international market identified Gujarat and Bengal as the two major export centers for cotton and silk textiles. The international market valued Indian textiles to be of high quality because they had strong durability and complex weaving patterns and colorful designs. The textiles had these qualities that made them capable of meeting various demands that arose in the international market.²¹ The exportation of textiles indicates that the activities of textile production occurred in a manner that was in line with the international markets before the European industrialization process began.

The process of textile production involves the use of skilled laborers who handle sophisticated industrial equipment. The spinning process of textile production begins with the preparation of cotton fibers that the laborers use with the charkha machine. The weaving process involves the use of sophisticated equipment to produce beautiful muslin and silk designs and strong calico textiles. The production and distribution processes were carried out through established merchant networks that created a system for coordinating them. The intermediaries extended credit to weavers while they established quality standards and coordinated the transportation system that carried large quantities of materials from production centers to distribution ports. The textile production centers in India established direct trade routes that connected the western ports of Gujarat to the river trade centers of Bengal. The textile distribution network in India established links between manufacturers and merchants who came from Arabia Persia East Africa and Southeast Asia.

The textile industry, through its production processes, illustrates that a craft production system can facilitate a large-scale business operation without relying on machine-based factories. The production processes of the textile industry were expanded to meet the demand of markets other than the local market to meet the demand of international markets for Indian textiles. The textile industry's production processes demonstrated flexibility in adapting to different rates of commercial expansion through its production processes.

²¹ K. N. Chaudhuri, *Trade and Civilisation in the Indian Ocean*, 201–205.

The international market's demand for Indian textiles illustrates that economic development is not dependent on the industrial base to support a high level of technological development. The economic significance of textile production to India functioned as an economic resource, and it supported the technological base for India's engagement in international trade networks of Afro-Eurasia.

IV. Military Technology and Gunpowder

The Indian military technology of the medieval period evolved through three processes which involved creating new methods and building new systems. The Delhi Sultanate and Vijayanagara Empire and Mughal Empire developed their territories through weapon advancements and fortification improvements and military system enhancements. The development of military technology in medieval India served as the main element which determined how countries fought wars because it affected their ability to create governmental systems and build public infrastructure and develop metalworking expertise.

- **Delhi Sultanate: The Genesis of Military Transformation**

The period between 1206 and 1526 when the Delhi Sultanate ruled India brought significant changes to the development of warfare in North India. The Sultanate adopted military practices from Central Asia which resulted in the introduction of mounted archery and composite bows and organized cavalry and iron weapons that changed the entire battlefield combat system. The new warfare system permitted soldiers to move quickly which created better combat possibilities than the previous system that required soldiers to fight in large groups with their elephants.²²

The construction methods used to build fortification walls experienced major changes. The defensive system improved through stronger wall construction and more secure gateway systems and architectural designs which enabled cities to endure extended siege periods. The fourteenth century saw the first development of gunpowder technology which remained unregulated at that time. The period between 1351 and 1388 when Firoz Shah Tughlaq ruled saw tests with various siege engine designs which demonstrated his interest in new military technology.²³ The Sultanate era lacked widespread artillery use but it provided a foundation for military advancements to

²²Satish Chandra, *History of Medieval India: 800-1700*, Orient Blackswan, 2007, pp146-150.

²³ Ibid.

spread throughout the Indian subcontinent. The Sultanate used its cavalry units and metalworking abilities and city defense systems to maintain control over its entire territory.

- **Vijayanagara: Adaptation and Defensive Innovation.**

The Deccan political system established the foundation which enabled the Vijayanagara Empire to create its military system which operated between 1336 and 1646 throughout southern India. Southern Indian warfare required military forces to maintain equal numbers of foot soldiers and cavalry soldiers and war elephants. The Vijayanagara Empire constructed protective systems which safeguarded cities like Hampi through their extensive stone wall network. The defensive structures exhibit their superior abilities in stone craftsmanship and geometric design and architectural planning through their multi-layered wall system which functions together with observation towers and protected entryways.²⁴

The Vijayanagara Empire developed its military system during the fifteenth and sixteenth centuries which incorporated gunpowder artillery because the Deccan Sultanates had already started using this technology. The military forces consisted of Turkish and Persian soldiers who specialized in the use of artillery. The military used cannons and ammunition which required metallurgical workshops to produce their new operational requirements. The situation indicates that technology was developed there because they had to find solutions to military challenges rather than maintaining a complete separation.

The Battle of Talikota (1565) demonstrates the importance of artillery and matchlock soldiers for the conflict between the Deccan Sultanates and the Vijayanagara Empire. The gunpowder technology at this point had fully changed the Deccan power dynamics.²⁵

- **Gunpowder Warfare Reported under the Mughal Empire**

Gunpowder warfare was formalized through a large aspect of the Mughal Empire. Babur's victory over the Lodi in the First Battle of Panipat in 1526 illustrated how effective the use of field artillery can be when combined with mobile cavalry fighting on the same battlefield. This method utilized

²⁴ George Michell and John Fritz, *Hampi: Monuments of the Vijayanagara Empire* (Cambridge: Cambridge University Press, 1981), pp35–42.

²⁵ Ibid

the transport of cannons via carts (araba form) as "combined" or "cooperative" capabilities of firepower during attacks by enemy forces from different locations.²⁶

Through the creation of specific units within the imperial karkhanas of the Mughal Empire, firearms and artillery (cannons and cannisters) became more sophisticated; forming different departments within the imperial karkhanas that produced different types of ammunition, and the artillery departments were responsible for the production (manufacturing) of major cannons (of bronze and iron), matchlocks, and siege artillery. Creating larger caliber cannons required the ability to melt, alloy, and transport iron and bronze to and from various geographical locations; so the Mughal Empire took advantage of local talent in metallurgy when developing successful military units.²⁷

Fortifications were also impacted by the development of gunpowder warfare; new types of defensive structures designed to repel cannon fire were created for fortifications through the development of large, solid walls of earth/dirt; small defensive structures (such as flanking towers); and inclined/buttressed bastions. Fortifications built in Agra and Lahore demonstrate the way that fortifications were designed to repel cannon fire as they relate to technological advancements in the methodology of gunpowder warfare.²⁸ Through history, fortifications were constructed simultaneously (in a short span of time) for both attacking and defending; and continued to be as long as need existed.

The military technology of the medieval India proves that the three kingdoms military systems were developed through a process of synthesis that involved borrowing elements from each other. The militarily technological aspect of medieval India shows that the three kingdoms had developed their military systems through a process of synthesis which entailed borrowing of elements from each other.

The Vijayanagara Empire continued the use of their artillery system without disrupting their entire military legacy from older times.

²⁶ Jos Gommans, *Mughal Warfare: Indian Frontiers and Highroads to Empire*, Routledge, 2002, pp52-56.

²⁷ Ibid.

²⁸ Stephen P. Blake, *Shahjahanabad: The Sovereign City in Mughal India*, Cambridge: Cambridge University Press, 1991, pp 97–102.

The Mughals created a formidable gunpowder warfare system based on their metallurgy achievements and their military operations.

More than a mere weapon, gunpowder technologies were “a complete socio-technical system involving the procurement of resources (iron, copper, and saltpeter), artisanal expertise, administrative policies, and financial backing”.²⁹ The deployment of gunpowder fire required vast architectural changes combined with the redistribution of the workforce and unification of empires. The knowledge transfer process through trans-regional network called for localized explanations along with institutional support to promote an information flow between different kingdoms. The military technology of the medieval India proves that innovative development takes its roots from the existing military system, and then the system adopts and implement the managerial structures. The evolutionary dynamics of gunpowder warfare prove that Indian kingdoms enhanced their military capacities through indigenous mechanisms that they devised. The kingdoms devised their own manufacturing and strategic systems by modifying the external technological systems that they imported from other countries.

Findings of the Study

1. Technology was socially embedded – The scientific progress of medieval Indian technological systems developed from the collaborative work of Indian rulers, artisans, peasants, merchants, and scholars. The transmission of knowledge occurred through the practice of hereditary craft traditions and apprentice programs and local educational institutions.
2. Technology strengthened state formation – The political power of medieval states received support from technological systems which included irrigation networks and military equipment and fortification systems. These technologies enabled rulers to exercise power over their territories while controlling taxation and expanding their dominions.
3. Agricultural expansion depended on irrigation systems – The tank irrigation systems of South India and the canal irrigation networks of North India established new agricultural paths which boosted agricultural output. The systems maintained stable food production which formed the economic foundation of medieval kingdoms.

²⁹ Bert S. Hall, *Weapons and Warfare in Renaissance Europe*, Baltimore: Johns Hopkins University Press, 1997, pp 168–173.

4. The artisanal industries brought economic development through their production of wootz steel and textiles which enabled trade with their output from Gujarat and Bengal regions. The Indian craftsmen established their international trade connections through Indian Ocean trade networks which operated between two different markets.

5. The development of military technology led to changes in warfare and military power dynamics. The Delhi Sultanate and Vijayanagara Empire and Mughal Empire adopted cavalry warfare and artillery and gunpowder weapons which changed their military patterns. The technological advancements enabled empires to expand their territories while maintaining effective defense systems.

6. The development of technology in medieval India showed adaptive capabilities during the Middle Ages. The study shows that medieval India was not technologically stagnant. The region developed new innovations through its environmental changes and social systems and international cultural connections.

The research shows that medieval Indian technological progress depended on state authority and social structure and economic activities. The society used irrigation systems and metallurgy and textile production and military innovations to create technologies that helped them grow their agriculture and generate more income and maintain political order.

The research shows that artisans and peasants and merchants together with local institutions played a crucial role in developing and sharing technological knowledge. The evidence shows that medieval India maintained active technological progress through social collaboration and ecological learning and international trade relations.

Conclusion

The historical development of technology demonstrates complex systems of technological advancements which operated throughout the entire medieval period in India when examined through the combined perspectives of government institutions, societal structures, and scientific knowledge. The development of state institutions and their financial systems depended on the technological systems which existed during both historical periods. Agricultural systems developed through irrigation system expansion which created new agricultural areas and increased agricultural production and revenue collection. The territorial control operations of fortifications combined with artillery systems to establish complete control of the region. The operation of

metallurgical and textile companies which existed during this time period created financial growth for the economy. The combination of architectural engineering and specialized technical skills through imperial projects established an official standard for technological advancement.

Technological systems operated as social structures during medieval India. The occurrence of technological advancements depended on the active participation of artisans, peasants, merchants, and members of society who created essential technological developments. The village assemblies controlled the village irrigation systems while craftsmen communities created new textile and metallurgical processes which merchants used to expand their trading activities. Scientific information spread through the use of Sanskrit and Persian and local languages while Indian Ocean trade routes enabled the distribution of maritime and architectural and military technology throughout the region.

The study demonstrates that state power and social systems and scientific methods work together to create technological development. The research proves that India during the Middle Ages achieved continuous and adaptive progress through its worldwide trade connections. The relationship between state power and social structures and scientific research enables medieval India to function as a participant in global technological changes while presenting a different historical progression model that exists outside European development patterns.

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